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MEASUREMENT OF SEA AND ICE BACKSCATTER REFLECTIVITY USING AN OTH RADAR SYSTEM

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) It is essential, during the operation of an OTH-radar system designed for the detection of small targets (aircraft or cruise missiles), that the operators be able to estimate the system sensitivity in real time without targets present. In geographical areas under surveillance that are remote and inaccessible, this technique involves measuring the ratio of the signal returned from the "ground" to the noise signal. Data from Polar Fox II experimental OTH radar system was analyzed in order to determine the intrinsic backscatter reflectivity from open ocean, sea ice, and the Greenland ice cap. The data for this study was		

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carefully selected so as to minimize the complexity introduced by the ionospheric propagation modes involved in reaching these areas from the radar site in northern Maine. It was considered essential that this analysis be carried out using ionospherically propagated signals with the associated fading, absorption, and so on, so that the results would be directly applicable to other OTH systems. The data was limited to midday periods for the 1972 Spring and Fall seasons. The selected azimuths and ranges were chosen so that comparisons could be made between the various backscatter media under the same propagation conditions. The azimuthal coverage was from 15° T to 60° T measured from the radar site at 46.8° N, 68.1° W, in six steps each 9° wide. The range varied from 1500 to 3100 km in order to cover the required land and sea areas. The data from the Spring was included so that the part of the coverage between Labrador and Greenland was sea ice.

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Measurement of Sea and Ice Backscatter Reflectivity Using an OTH Radar System

1. INTRODUCTION

The characteristics of radio waves that are backscattered from the earth's surface have interested observers for many years because of their potential to yield significant information about the scattering surface. An example would be the recognition of coastal regions or islands by the different scattering characteristics of land and water. The technique has been pursued to develop a method of remote sensing of sea states[1] including wave heights and wind direction by studying the dominant peaks in the observed Doppler spectrum. The interest in this study is to quantify the surface reflectivity of sea water, sea ice, and the Greenland ice cap so they may serve as standards or references for calibrating the sensitivity of a High Frequency (HF), Over-the-Horizon radar when there are no aircraft targets of opportunity to serve as calibration sources. With these calibrated surfaces the system performance could be assessed at any time or place.

(Received for publication 11 March 1982)

1. Barrick, D.E., Headrick, J.M., Bogle, W.W., and Crombie, D.D. (1974) Sea backscatter at HF: Interpretation and utilization of the echo, Proc. of the IEEE, 62(No. 2).

2. DATA ANALYSIS

The source of data for this study was the Polar Fox II experimental backscatter radar which was operated in northern Maine by the Raytheon Company under Air Force sponsorship for a twelve-month period in 1971-1972. The portion of the coverage area that is pertinent to this study is shown in Figure 1. The experiment used a high power pulsed radar (800 kW peak) operated at 30 pulses per sec with a 10 kHz chirp bandwidth. Radar parameters are listed in Table 1.

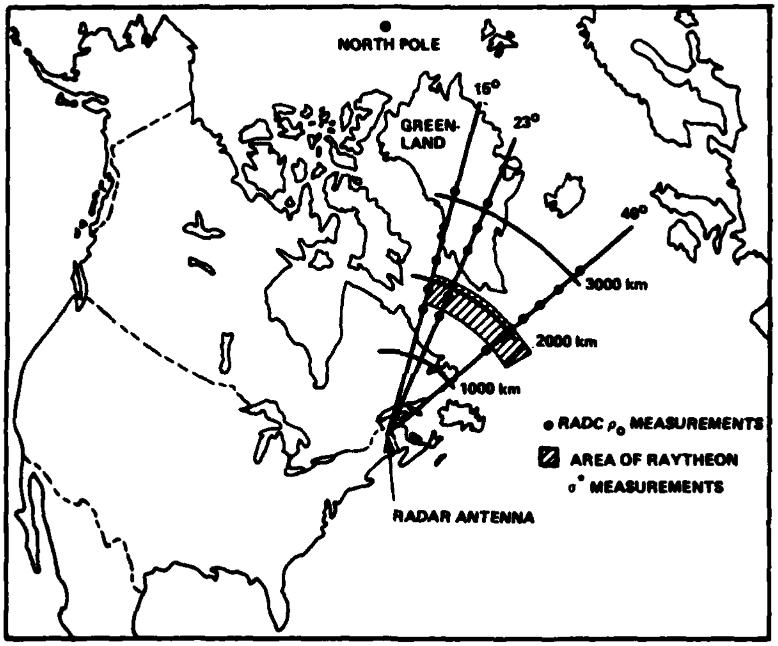

Figure 1. Coverage of the Polar Fox II Radar

The 49° azimuth was selected as a source of sea water returns at all ranges at all times of the year. The 15° and 23° azimuths provided sea ice returns at the shorter ranges (1600, 1800, and 2100 km) during the selected intervals of the winter and spring months. The determination of whether the scattering area consisted of sea ice or water was based on ice analysis charts for the period of operation prepared by the USN FLEWEAFAC, SUITLAND, MD. The 15° and 23° azimuths were also the source for the Greenland ice cap scattering surface at the longer ranges.

Table 1. Radar Parameters

Location	Caribou, Maine. 47° N 68° W
Frequency	Selectable in the band 6 to 26 MHz
Power	64 kW avg. 800 kW peak
Range Resolution	15 km
Receive Beamwidth	7 degrees at 12 MHz
Azimuth	11 steps from -30° T to +60° T
Measurement	1 min/Freq/Beam Position/Hour

By sampling and comparing data at the same ranges on all azimuths included in the study, an attempt was made to eliminate any dependence on elevation angle. The original Polar Fox II experiment required that this radar be located so as to include the auroral oval in its coverage area but for purposes of this reflectivity study it is preferable to select data such that they are not affected by propagation anomalies. This consideration dictated that the data be limited to the mid-day, 17-19 UT, period (13-15 local time in the coverage area).

The data selected for this study were limited to F-region propagation modes in order to insure confidence in our description of the propagation loss and antenna gain factors involved in the analysis of the received signals. For the same reason it was decided to avoid the sometimes anomalous propagation conditions associated with the summer day time by limiting the data base to March, April, September, October, and November. Radar data were available for a total of thirty days over the five-month period.

The analysis begins with the measurement of the received backscatter power and then with the receiver calibration, antenna gain patterns, transmitter power and the assumed ionospheric parameters for estimating propagation angles and absorption losses, the surface reflectivity (ρ_o) is computed using the radar equation.

$$\rho_o = \frac{(4\pi)^3 R^4 (L^2)^2}{P_T G_T G_R \lambda^2 \tau (R\phi)} P_R \,(m^2/m^2)$$

where

R = range to the reflecting surface

P_R = received backscatter power

L = ionospheric loss (one leg)

P_T = transmitted power

G_T = transmit antenna gain

G_R = receive antenna gain

λ = wavelength of observing frequency

τ = pulse width

ϕ = azimuthal beamwidth .

The ionospheric loss term is derived using the method of George and Bradley.[2] Antenna gain factors were obtained from measurements performed in a cooperative program by Raytheon, Lincoln Laboratory[3] and the Rome Air Development Center.[4]

To insure that the selected backscatter data was propagated by a one-hop F (1F) mode it was necessary to review manually the range/Doppler characteristics of the received signals. The receiver signal for a given azimuth measurement is displayed in the format shown in Figure 2. Here the Doppler spectrum over ± 15 Hz and 45 km range steps is presented by printing the magnitude of the received power (-d BW) in the appropriate range/Doppler location. This provides a pictorial overview of the received power in a two dimensional format. To be accepted as 1F-propagated surface clutter the energy had to be concentrated in the narrow band centered on 0 Hz and be part of a continuum of signals over a range interval appropriate for F mode coverage. In the example shown, clutter from ionospheric irregularity produced measurable returned power at all Doppler frequencies in the range interval from 900 to 1300 km (outside the area of interest for this study). Ground clutter returns start around 2100 km and continue to 3400 km.

Additional criteria were imposed on the data selection which can best be described by visualizing the received power at 0 Hz Doppler, as a function of range as shown in Figure 3. To be included in the data base used for this study, a received power sample had to occur at a range where the ground backscatter signal was fully developed, that is, not on the leading edge and more than 10 dB above the noise level.

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2. George, P.L., and Bradley, P.A. (1974) A new method of predicting the ionospheric absorption of high frequency waves at oblique incidence, ITU Telecommunication Journal, Geneva.

3. Nichols, B.E. (1973) Propagation Measurements Program (Polar Fox II) Antenna Patterns and Gains. Lincoln Laboratory Project Report PMP-6, AD 896788L.

4. Parry, J.L. (1973) Antenna Pattern Measurements Project 1765, RADC-TR-73-32, AD 909689L.

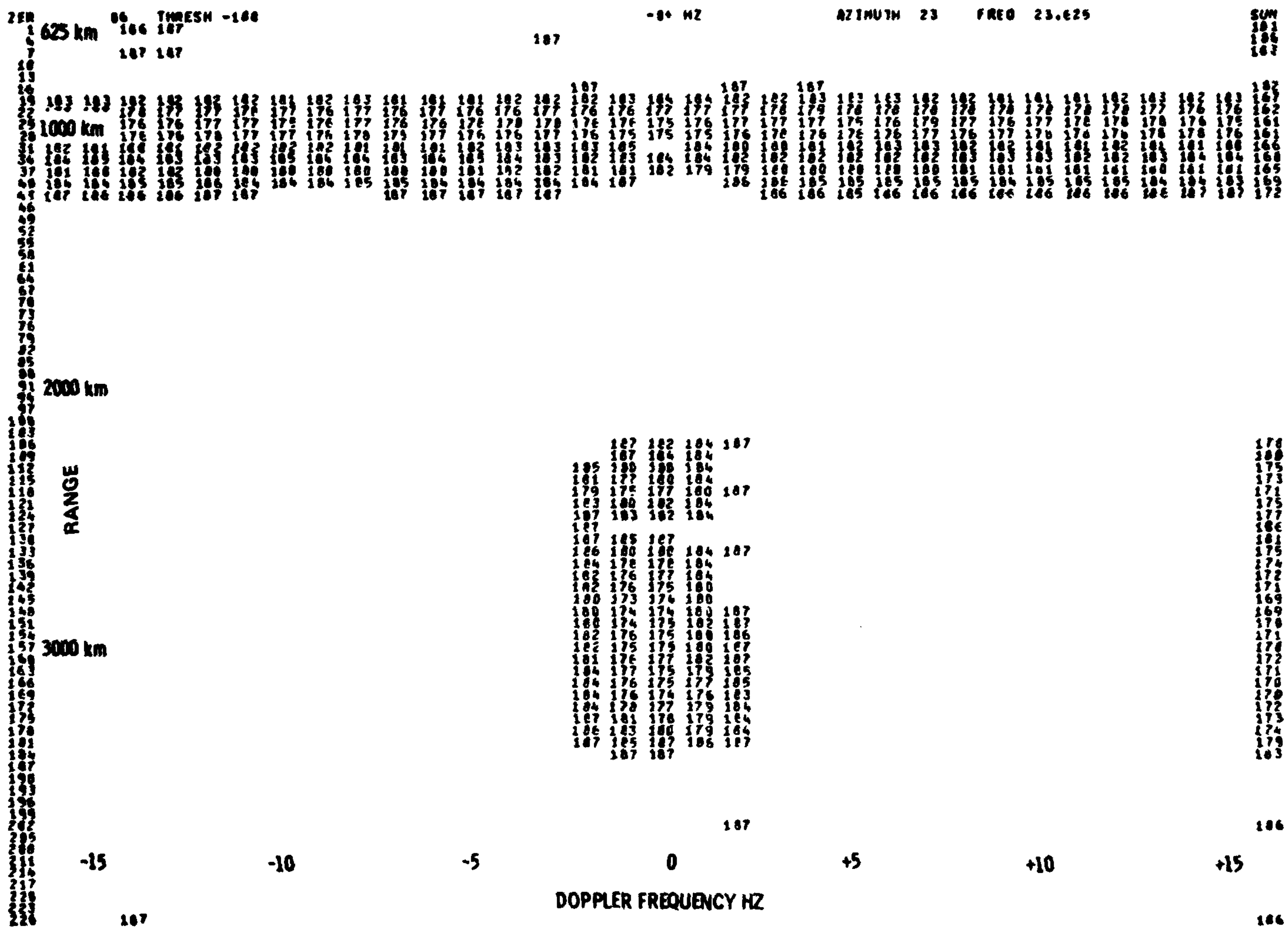

Figure 2. One Minute Sample of Radar Data

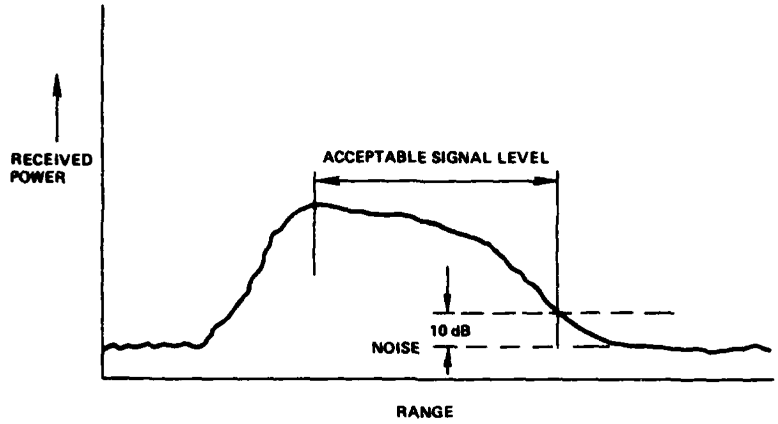

Figure 3. Typical Ground Clutter Signal

2.1 Backscatter Reflectivities

The values shown in Table 2 were determined using the relationship for surface reflectivity described above. These values represent the upper decile of the data available from 90 hr of observations. The spread of the individual measurements below the upper decile was consistently of the order of 20 dB independent of the scattering medium, including the Greenland ice cap. The upper decile value is cited so that observed variability below that level can be explained as the result of various loss factors.

Table 2. Upper Decile Values of Surface Reflectivity dB (m^2/m^2)

Frequency	12 MHz	15 MHz	19 MHz	24 MHz
Surface				
Sea Water	-22	-24.5	-20	-23
Sea Ice	-34	-39		
Ice Cap			-34	-37

2.2 Temporal Variations

In an attempt to measure temporal structure of the variations in reflectivity, the signals 1 min apart from adjacent azimuth beams (9° corresponds to 300 km transverse distance at the range of interest) were compared. Under these conditions

the scatter of the data points was substantially the same as previously measured. Unfortunately, it is not possible to sample more frequently than once per hour at exactly the same azimuth. To the extent that this 9° azimuthal change can be considered small and since the motionless ice cap shows the same variability, these 1-min fluctuations appear to be characteristic of the ionospheric propagation path and loss factors. Some of the major contributors to the spread in these measurements would include polarization, absorption and F-region irregularities. These factors, particularly absorption (auroral) and F-region irregularities, are certainly enhanced by the proximity to the auroral zone, even in daytime.

2.3 Azimuthal Variations

If all equipment and propagation factors had been properly taken into account, it is reasonable to expect a constant reflectivity for a given surface type (for example, sea water) independent of observing azimuth. This did not prove to be true when reflectivies at azimuths of 15°, 23° and 49° were compared using data from September when sea water was present in the 1600-2100 km range segment. In order to understand this unexpected result the Raytheon analysis of the Polar Fox II data which produced a reflectivity value σ^*, for every 75 km range interval was examined. One significant difference is that the σ^* values do not contain an ionospheric loss term and thus, what is measured is ρ_o with loss or $\rho_o/(L_2)^2$. These σ^* values, taken over the range interval from 1600 to 2050 km and at azimuths of 15, 23, 31, 40, 49 and 60 degrees provided a sizable data base for this investigation of the azimuthal dependence of reflectivity. For a given range the ratios of reflectivity for different azimuths were compared and the results showed the same azimuthal variation as the ρ_o values. There is good agreement between the Raytheon analysis and the work presented here.

Because the azimuthal variation of reflectivities is strikingly similar to the azimuthal antenna patterns a careful review was made to insure that the antenna measurement results were reasonable and had been correctly incorporated in the reflectivity calculations. The validity of the antenna considerations having been confirmed, there remains an unexplained but apparently real azimuthal or latitudinal variation of sea water backscatter reflectivity as shown in Figure 4. Assuming constancy of the reflective properties of the sea and accepting the validity of the antenna pattern measurements, it is necessary to compensate for this observed azimuthal variation. Although the source of this assumed propagation loss mechanism, which increases in a northerly direction, is presently undetermined, the 12 and 15 MHz reflectivity values have been corrected for it and these corrected values are shown in Table 3.

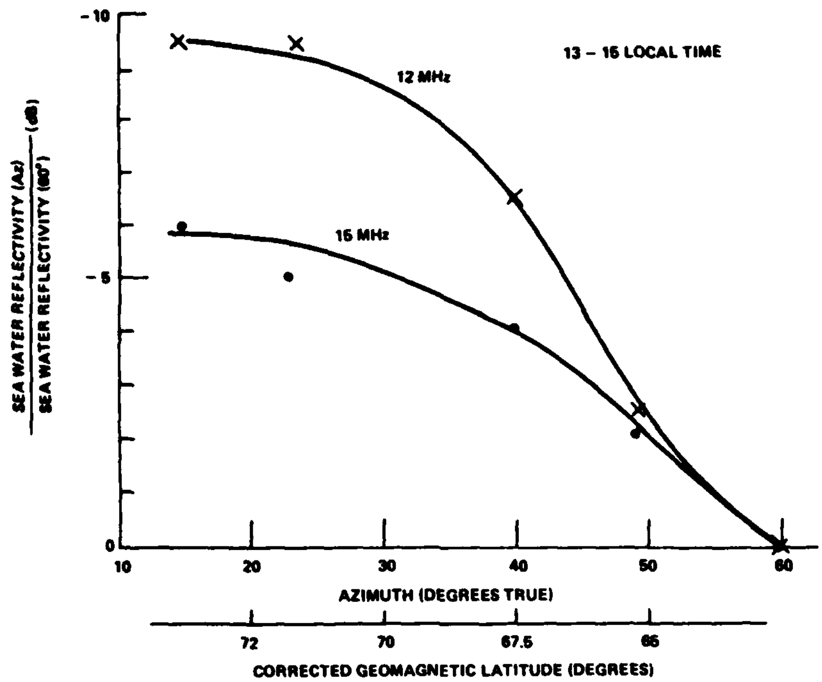

Figure 4. Azimuthal Dependence of Sea Water Reflectivity

Table 3. Corrected Upper Decile Values of Surface Reflectivity dB (m^2/m^2)

Frequency	12 MHz	15 MHz	19 MHz	24 MHz
Surface				
Sea Water	-17	-20	-20	-23
Sea Ice	-25	-34		
Ice Cap			-31	-35

It can be seen from Figure 5 that the 12- and 15-MHz absorption values are in good agreement with a frequency dependence of f^{-2} and this relationship was used to correct the 19- and 24-MHz reflectivity values in Table 3. Since the sea water reflectivity values at 19 and 24 MHz come only from the 49 degree azimuth, these values are unchanged.

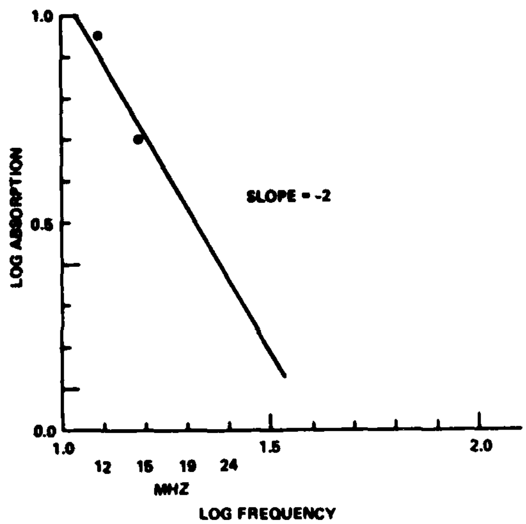

Figure 5. Frequency Dependence of Azimuthal (Latitudinal) Absorption

3. DISCUSSION

The upper decile value of reflectivity of sea water approaches -17 dB m^2/m^2 with little variation with frequency over the range of 12-24 MHz in these observations. The upper decile value is cited so that observed variability below that level can be explained as the effect of the various loss factors. Theory[5] predicts that the first order scattering coefficient should be approximately -17 dB independent of sea state or frequency, in this region of the HF band. The independence of reflectivity with sea state is attributed to the fact that the waves effective in the scattering process are half the radar wavelength, or 6.5 to 12.5 m for this study, and waves of these lengths are almost always present and fully developed to their maximum height on the open ocean in the North Atlantic.

Because of the location of the sea ice and ice cap regions, only narrow bands could be used for illumination so inferences as to frequency dependence are impossible. It is clear that the radar scattering cross section of both these media are significantly below that of the open sea.

Perhaps the most interesting result of this study is the azimuthal or latitudinal variation. If it is assumed that this variation is due to auroral absorption an inconsistency arises when the data is compared to the measurements of Hartz et al[6] or

5. Barrick, D.E. (1972) First order theory and analysis of MF/HF/VHF scattering from the sea, IEEE Trans. Antenna and Propag., AP-20:2-10.
6. Hartz, T.R., Montriand, L.E., and Vogan, E.L. (1963) A study of auroral absorption at 30 MHz, Can. J. Phys. 41:581.

predictive models by Foppiano[7] and Basler.[8] These measurements and models do not show a consistent increase in absorption from 65 to 72 degrees geomagnetic latitude as reflected in the present data. The thoroughness of the antenna measurement effort and the reasonableness of the antenna pattern results require, however, the postulation of some loss (ionospheric absorption or scattering) mechanism.

4. CONCLUSION

The radar scattering cross section of open sea water, sea ice, or the Greenland ice cap are sufficiently predictable to be useful in calibrating the system sensitivity of an OTH radar. Questions that remain to be answered concern the variance in these backscattered signals as a function of averaging time and the geographical area illuminated.

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